Workbook | 2021

AP® Physics 1

Workbook | 2021

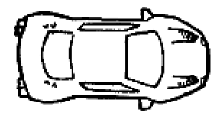
Unit 3 - Circular Motion and Gravitation

NAME ______________________________ DATE ______________

Scenario

Angela is in a stopped car at a traffic light when the light turns green and she accelerates.

Using Representations



PART A: Sketch and label vectors for velocity, acceleration, and net force on the car. (This is NOT a free-body diagram.)

Which way does Angela's body "feel" pushed? Explain in a short sentence why she feels this way.

She feels pushed ______________ because ______________________________

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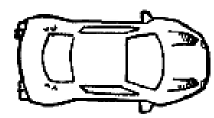


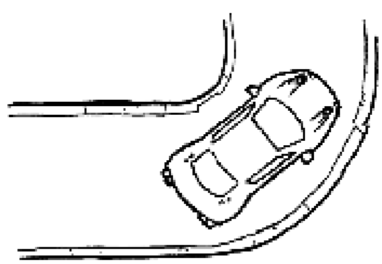
PART B: As she approaches a stop sign, she slams on the brakes. Sketch and label vectors for velocity, acceleration, and net force on the car. (This is NOT a free-body diagram.)

Which way does Angela's body "feel" pushed? ______________________________

Which way is the car accelerating? ______________________________

Which direction is the net force on the car? ______________________________

PART C: As Angela continues driving, she rounds a corner at a constant speed. Sketch and label vectors for velocity, acceleration, and net force on the car. (This is NOT a free-body diagram.)



Which way does Angela's body "feel" pushed? ______________________________

Which way is the car accelerating? ______________________________

Which direction is the net force on the car? ______________________________

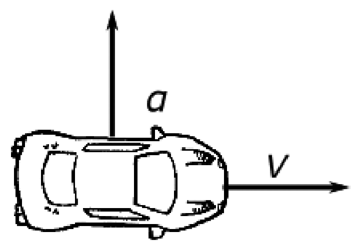
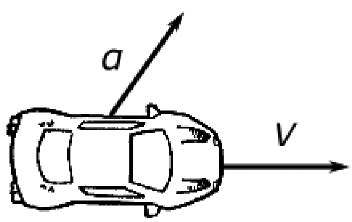
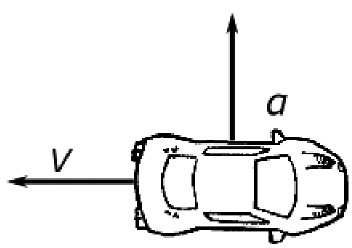
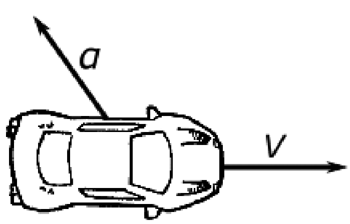
NAME ______________________________ **DATE** ________________

Scenario

A car is traveling along a long road. Air resistance can be ignored.

Using Representations

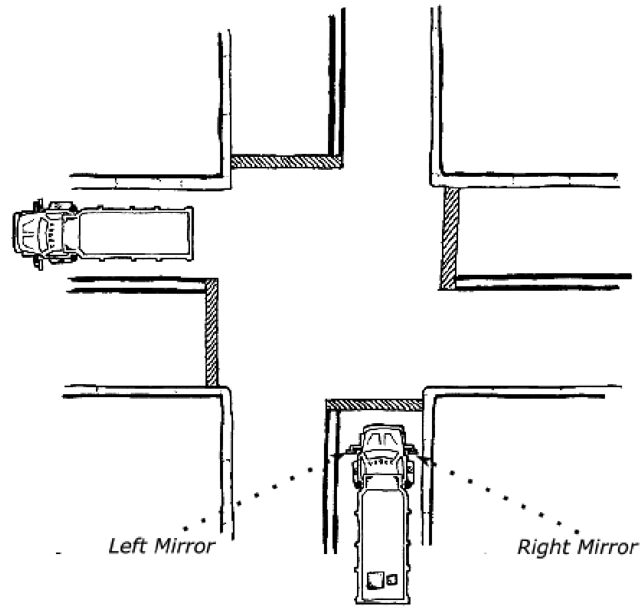
PART A: For the following situations, determine if the car is speeding up, slowing down, or staying at a constant speed and turning clockwise, counterclockwise, or not turning.

Physical Scenario	*Speeding Up/ Slowing Down/ Constant Speed*	*Turning Clockwise/ Turning Counterclockwise/ Not Turning*
		
		
		
		

NAME ______________________ DATE ______________

Scenario

A dump truck is making a very fast left turn as shown. In the back are two blocks of ice, one mass M *and one mass* m (M > m). *The truck does not roll over.*



Using Representations

PART A: Sketch the paths that the left and right mirrors take during the turn.

PART B: Using two different colors, sketch the paths that the two blocks of ice take during the turn. Assume that friction between the bed of the truck and the ice may be neglected.

Argumentation

PART C: Your friend, who is not in physics class, says the blocks go to the outside of the truck because a centrifugal force is acting on them. In a few brief sentences, explain why your friend is incorrect. Reference the diagram above in your answer.

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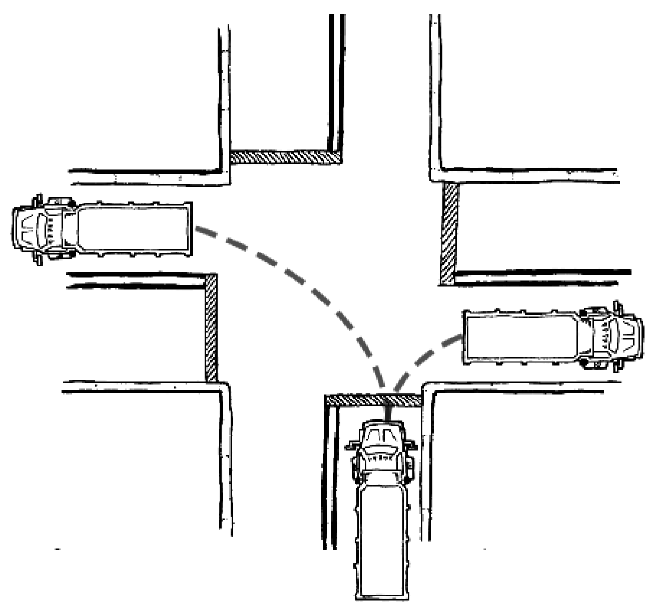
PART D: The truck then approaches another intersection to make a turn. The truck can either make a left turn or a right turn as shown in the diagram. Assume that the truck approaches, makes the turn, and continues in the new direction all without changing speed.



The centripetal force for the turn is provided by the force of static friction, which is determined by the relationship $F_{fs} = \mu_s F_N$. In a few short sentences, explain why the force of static friction, and not kinetic friction, is exerted on the truck even though the truck is in motion.

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PART E: In a few short sentences, explain what happens if the value of $\frac{mv^2}{r}$ is greater than the value of $\mu_s F_N$.

PART F: Which turn (left or right) requires the truck to slow down more in order to make the turn safely? Explain your answer using appropriate relationships.

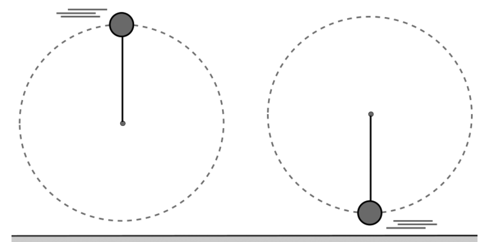
Checklist:

- ________ I answered the question directly.
- ________ I stated a law of physics that is always true.
- ________ I connected the law or laws of physics to the specific circumstances of the situation.
- ________ I used physics vocabulary (force, mass, acceleration, coefficient, velocity, speed, time, radius).

NAME ______________________ DATE ______________

Scenario

A ball whose weight is $2\ \mathrm{N}$ *is attached to the end of a cord of length* $2\ \mathrm{m}$ *as shown. The ball is whirled in a vertical circle clockwise. The tension in the cord at the top of the circle is* $7\ \mathrm{N}$*, and the tension at the bottom is* $15\ \mathrm{N}$*. Two students discuss the net force on the ball at the top of the circle.*



Dominique: "The net force on the ball at the top position is $7\ \mathrm{N}$ since the net force is the same as the tension."

Carlos: "No, the net force on the ball includes the centripetal force, tension, and weight. The tension and the weight are acting downward and have to be added. Then you need to figure out the centripetal force $\left(\frac{mv^2}{r}\right)$ and include it in the net force."

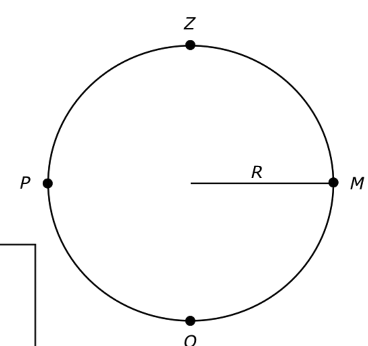
Analyze Data

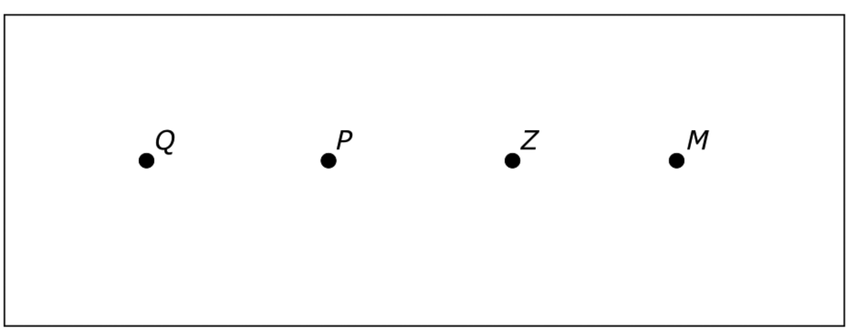
PART A: Cross out the incorrect statements for each student's argument.

PART B: In a few short sentences, state the net force on the ball at the top of the circle and support your claim with evidence.

Using Representations

PART C: The diagram at right shows the circular path of the ball from Part A. The dots below represent the ball at the marked locations on the circular path. Draw free-body diagrams showing and labeling the forces (not components) exerted on the ball at each point. Draw the relative lengths of all vectors to reflect the relative magnitudes of all the forces.





Quantitative Analysis

PART D: Derive an expression for the minimum speed the ball can have at point Z without leaving the circular path. For each line in the derivation, explain what was done mathematically. The first line is completed for you as an example.

$\sum F = ma_c$	The sum of the force is equal to ma, and since the ball is in circular motion, a is the centripetal acceleration.

PART E: Suppose the ball breaks at point P. Describe the motion of the ball after the string breaks. (When describing the motion of an object, you need to discuss what is happening to the position, velocity, and the acceleration of the object.) Tell the story of the motion of the ball from the time the string breaks until the ball reaches the ground.

Position:

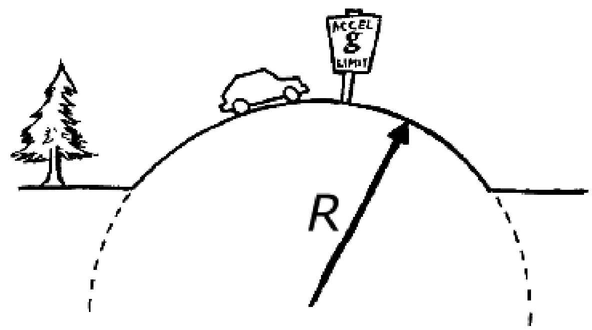
Velocity:

Acceleration:

NAME ______________________ DATE ____________

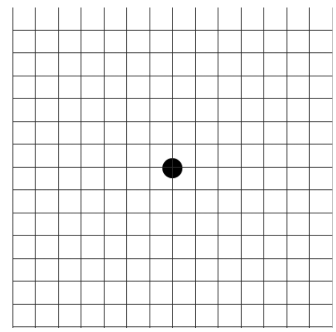
Scenario

A car of mass m *passes over a bump in a roadway that follows the arc of a circle of radius* R *as shown.*



Using Representations

PART A: The dot, at right below the picture, represents the car at the top of the hill. Draw a free-body diagram showing and labeling the forces (not components) exerted on the car. Draw the relative lengths of all vectors to reflect the relative magnitudes of all the forces. Each force must be represented by a distinct arrow starting on and pointing away from the dot.



Quantitative Analysis

PART B: Starting with Newton's second law, derive an expression for the maximum speed v the car can have without losing contact with the road. For each line of the derivation, explain what was done mathematically (i.e., annotate your derivations). Your expression should be in terms of R and physical constants.

$\sum F = ma$	The net force on the car at the top of the hill is equal to the acceleration of the car times the mass of the car.

Argumentation

PART C: In your derivation, you set the normal force equal to zero. Explain why.

PART D: A truck of mass 2 m passes over the same bump. Compared to the car, how many times bigger or smaller is its maximum speed without losing contact with the road? Justify your answer with reference to your expression in Part B.

Checklist:

- ________ I answered the question directly.
- ________ I stated a law of physics that is always true.
- ________ I connected the law or laws of physics to the specific circumstances of the situation.
- ________ I used physics vocabulary (force, mass, acceleration, centripetal, velocity, speed, time, radius).

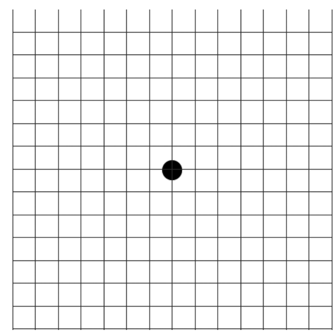
NAME ______________________________ DATE ______________

Scenario

A police car of mass m moves with constant speed around a curve of radius R. (The car is, from your point of view, coming out of the page and is in the process of turning towards the left side of the page.) The car is moving as fast as it can without sliding out of control on the flat roadway to respond to an emergency. This maximum safe speed is v_0. The coefficient of static friction between the car's tires and the roadway is μ_s.

Using Representations

PART A: The dot at right represents the car. Draw a free-body diagram showing and labeling the forces (not components) exerted on the car as it rounds the corner. Draw the relative lengths of all vectors to reflect the relative magnitudes of all the forces. Each force must be represented by a distinct arrow starting on and pointing away from the dot.



Argumentation

PART B: i. Suppose that the car encounters a wet section of the curved roadway so that this section of the curve has a coefficient of friction less than μ_s. The maximum safe speed to make this turn is v_1. Mark the correct relationship between v_0 and v_1.

_______ $v_1 < v_0$ _______ $v_1 = v_0$ _______ $v_1 > v_0$

Explain your reasoning using physical principles without manipulating equations. (This means you may reference equations from the equation sheet but should not derive an equation for the relationship between μ and F_N.)

ii. Suppose that the police car arrives at another section of roadway that also curves but has a radius of curvature greater than R. The maximum safe speed to make this turn is v_2. Mark the correct relationship between v_0 and v_2.

_______ $v_2 < v_0$ _______ $v_2 = v_0$ _______ $v_2 > v_0$

Explain your reasoning using physical principles without manipulating equations. (This means you may reference equations from the equation sheet but should not derive an equation for the relationship.)

Quantitative Analysis

PART C: Derive an expression for the maximum safe speed that the car can take the turn in terms of μ and R.

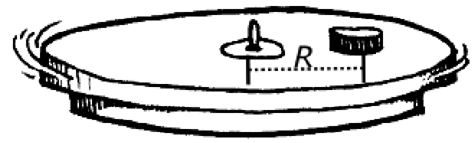
PART D: i. Explain how your expression in Part C supports your answer for Part B (i).

ii. Explain how your expression in Part C supports your answer for Part B (ii).

NAME ______________________ DATE ______________

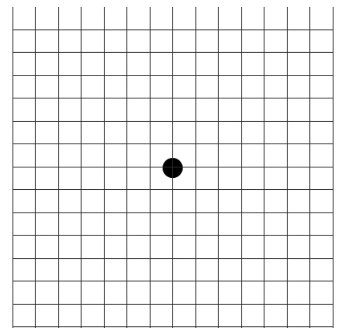
Scenario

Consider a coin of mass m *placed on a rotating surface a distance* R *from the axis of rotation. The surface rotates with a period* T. *There are some locations on the surface where the coin can be placed and the force of static friction will not allow the coin to slip. At other locations, the coin will slip because static friction is not strong enough to prevent the coin from slipping. The coefficient of static friction between the coin and the surface is* μ.



Using Representations

PART A: The dot at right represents the coin when the coin is at the location shown above in the diagram. Draw a free-body diagram showing and labeling the forces (not components) exerted on the coin. Draw the relative lengths of all vectors to reflect the relative magnitudes of all the forces. Each force must be represented by a distinct arrow starting on and pointing away from the dot.



Create an Equation

PART B: Starting from the equation $F_f \leq \mu F_N$, an inequality has been derived that must be satisfied at all times that the coin does not slip on the surface. The derivation has been done for you. You must fill in the annotations to explain each step.

$F_f \leq \mu F_N$	
$F_f \leq \mu mg$	
$\frac{mv^2}{R} \leq \mu mg$	
$\frac{v^2}{R} \leq \mu g$	
$v^2 \leq \mu gR$	
$v \leq \sqrt{\mu gR}$	
$\frac{4\pi^2 R}{T^2} \leq \mu g$	

Argumentation

Blake and Carlos are trying to predict whether the coin will slip if the coin is “too close” to or “too far” from the axis of rotation. The students reason as follows:

Blake: “I think that the coin will slip if it is too close to the axis. It is like if a car takes a turn too tightly, the car can slide out of control. There’s not enough force if the radius is too small.

Carlos: “I think that the coin will slip if it is too far from the axis. It’s like a merry-go-round; if I ride a merry-go-round near the center, then I don’t feel much force pulling me to the outside, but if I ride near the outside, there is more force pulling me away from the axis.

PART C: For each student’s statement, state whether the inequality written in Part B provides support for that statement. If so, explain how. If not, explain why not. Ignore whether the student’s statement is correct or incorrect for this part.

Blake’s Statement	***Carlos’s Statement***

PART D: State whether the coin will slip when it is “too close” to or “too far” from the axis.

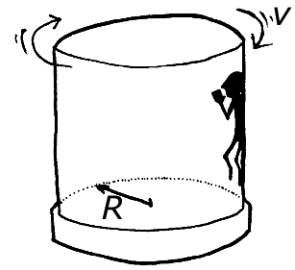
________ too close ________ too far

PART E: Angela and Dominique are arguing over how the mass of the coin affects whether it will slip or not. Angela believes that a lighter coin is less likely to slip because a lighter coin requires less force. Dominique believes that a heavier coin is less likely to slip because a heavier coin can have a greater amount of friction. Using your equations along with other physical principles, explain how the coin’s mass affects its likelihood of slipping.

NAME ____________________ **DATE** ____________

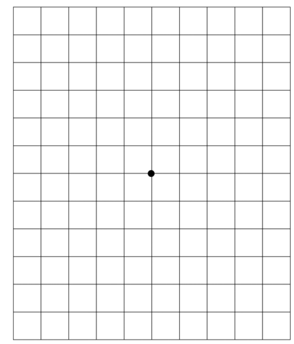
Scenario

Carlos (mass m*) enters the carnival ride called the "Rotor." The ride begins to rotate, and once Carlos has reached speed* v*, the floor drops out and he does not slip.*



Using Representations

PART A: The dot at right represents the student on the ride after the floor has dropped out. Draw a free-body diagram showing and labeling the forces (not components) exerted on the student. Draw the relative lengths of all vectors to reflect the relative magnitudes of all the forces. Each force must be represented by a distinct arrow starting on and pointing away from the dot.



Create an Equation

PART B: Derive an equation for the normal force on Carlos after the floor has dropped out. For each line of the derivation, explain what was done mathematically (i.e., annotate your derivation). Express your answer in terms of m, v, R and physical constants as appropriate.

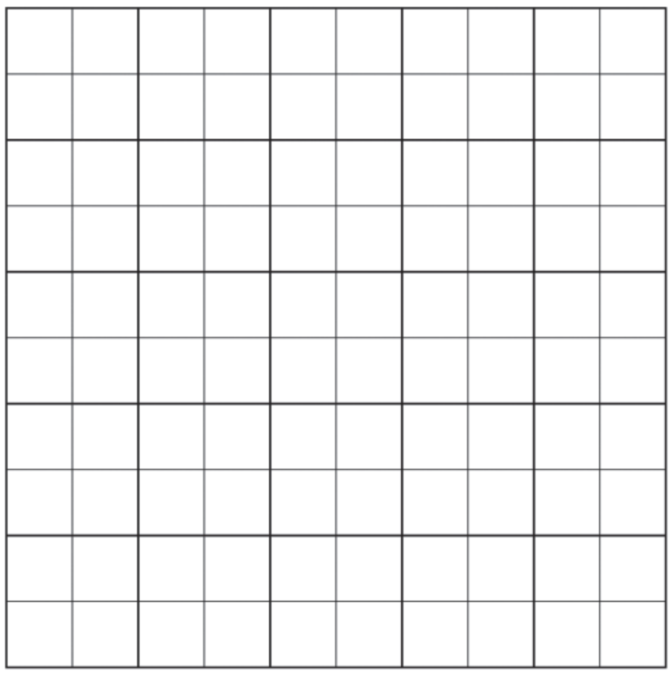
Data Analysis

On the next ride, Carlos takes a force sensor and places it between himself and the wall of the ride and collects the following data about the force from the wall and the speed of the ride:

Force from the Wall *(N)*	***Speed of the Ride*** *(m/s)*	
190	5	
540	8	
840	10	
1,225	12	
1,850	15	

PART C: Which quantities should be graphed to yield a straight line whose slope could be used to determine the radius of the ride? Justify your answer. You may use the remaining columns in the table above, as needed, to record any quantities (including units) that are not already in the table.

PART D: Plot the graph on the axes below. Label the axis with the variables used and appropriate numbers to indicate the scale. Draw a best-fit line and find the slope of the line.

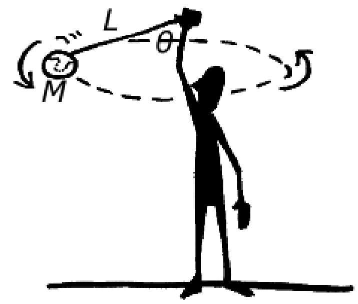


PART E: Using the slope calculated in Part D, determine the radius of the ride if Carlos's mass is 50 kg.

NAME ______________________________ DATE ______________

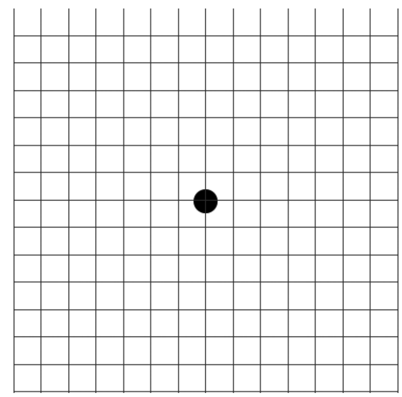
Scenario

Consider a ball of mass M connected to a string of length L. A student holding the free end of the string whirls the ball in a horizontal circle with constant speed. The angle between the string and the vertical is θ. The student attempts to whirl the ball faster and faster in order to make the string become horizontal. No matter how fast the student whirls the ball, the string is never exactly horizontal.



Using Representations

PART A: i. The dot below represents the ball at the instant it appears in the diagram. Draw a free-body diagram showing and labeling the forces (not components) exerted on the ball. Draw the relative lengths of all vectors to reflect the relative magnitudes of all the forces.



ii. By discussing specific features of your force diagram, explain why the rope cannot become completely horizontal no matter how fast the ball is whirled.

Create an Equation

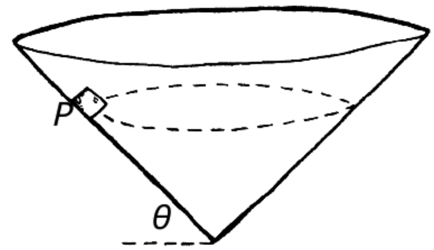
PART B: i. Derive an equation that relates the speed v of the ball in its circle to the string length L and angle θ. [Hint: What force component provides the centripetal acceleration? How can you find the radius of the circle in terms of L and θ?]

ii. How does your equation in Part B (i) show that the rope cannot become horizontal no matter how fast the ball is whirled?

NAME ______________________________ DATE ______________

Scenario

Consider a cone made of a material for which friction may be neglected. The sides of the cone make an angle θ with the horizontal plane. A small block is placed at point P. In Case 1, the block is released from rest and slides down the side of the cone toward the point at the bottom. In Case 2, the block is released with initial motion so that the block travels with constant speed along the dotted circular path.



Data Analysis

PART A: In Case 1, the block is released from rest. Is the block accelerating?

________ Yes ________ No

Explain, and if yes, determine the direction of the acceleration.

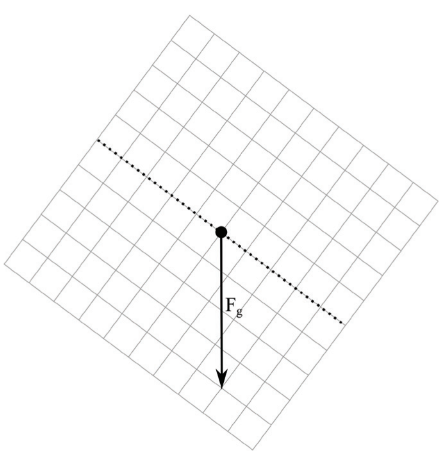
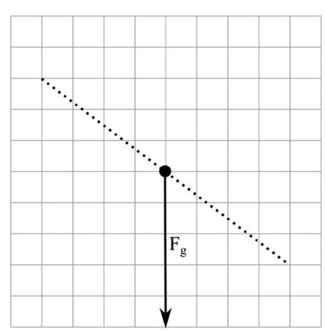
In Case 2, the block is released so that it travels with a constant speed along the dotted circular path. Is the block accelerating?

________ Yes ________ No

Explain, and if yes, determine the direction of the acceleration.

Using Representations

PART B: In both diagrams below, the weight F_g of the block is drawn. Draw the normal force exerted in each case on the corresponding diagram. Use the grids provided to make each normal force have the proper length. (In each case, breaking one of the forces into components will help you find the direction of the acceleration.)

Case 1	***Case 2***
	

Quantitative Analysis

PART C: Derive an expression for the magnitude of the normal force exerted on the object in each case in terms of F_g, θ, and physical constants as necessary.

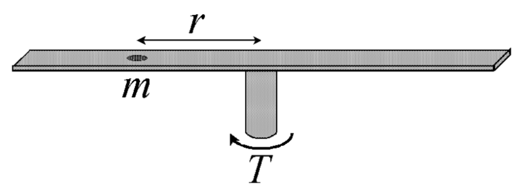
Case 1	***Case 2***

PART D: Use the diagrams in Part B to explain why the normal force is greater in Case 2. Then use your equations in Part C to explain why the normal force is greater in Case 2.

NAME ______________________ DATE ______________

Scenario

A student is attempting to determine the coefficient of static friction μ_s between a coin and a steel plate. The student attaches the center of the plate to a freely rotating axis. For each trial, the student sets the coin on different positions on the steel plate and measures the distance r from the center of the coin to the center of the axis of rotation. The student also has a stopwatch to measure the period T of the plate's rotation.



Experimental Design

PART A: Explain how the student can use this setup to take measurements that would allow the coefficient of static friction to be calculated. Be sure to explain clearly what rotational period must be measured and how experimental error can be reduced.

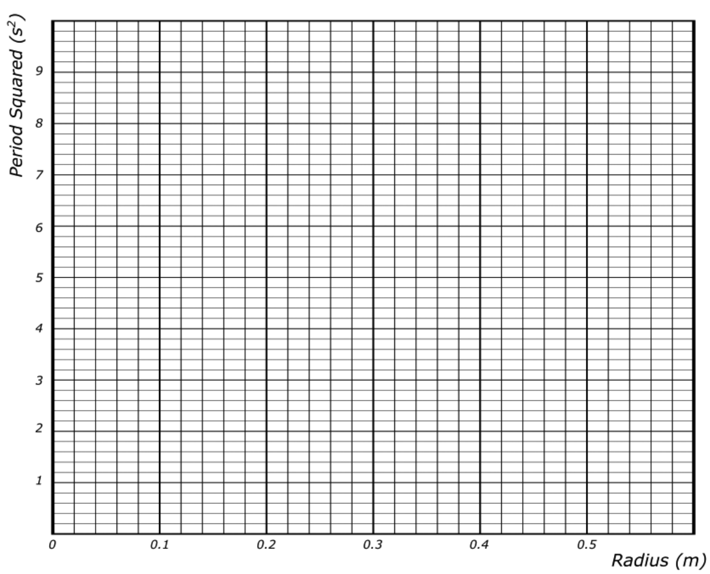
Quantitative Analysis

PART B: Starting with Newton's laws and basic equations for circular motion, derive an equation that relates μ, r, T, and fundamental constants.

The student collects the data shown in the table above.

PART C: Plot the data on the T^2 vs. r graph shown below. Draw a best-fit line to the data and calculate the slope of the best-fit line.

r (m)	T (s)	T^2 (s^2)
0.1	1.4	1.96
0.2	2.0	4.00
0.3	2.3	5.29
0.4	2.7	7.29
0.5	2.9	8.41

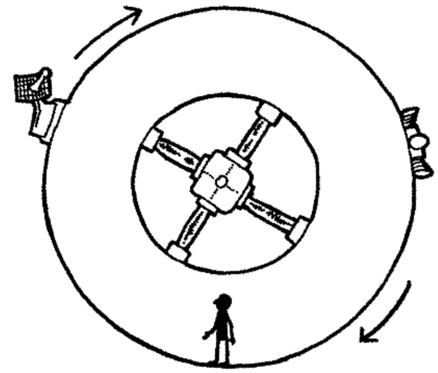


PART D: Use your equation from Part B along with the slope of your best-fit line from Part C to calculate the value of μ.

NAME ______________________ DATE ____________

Scenario

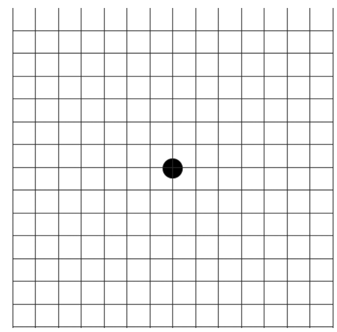
A doughnut-shaped space station is built far away from the gravitational fields of Earth and other massive bodies. For the comfort and safety of the astronauts, the space station is rotated to create an artificial internal gravity. The rotation speed is such that the apparent acceleration due to gravity at the outer surface is $9.8\ \mathrm{m/s^2}$. *The space station rotates clockwise.*



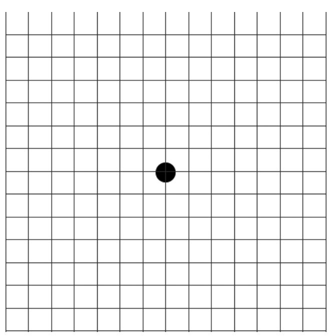
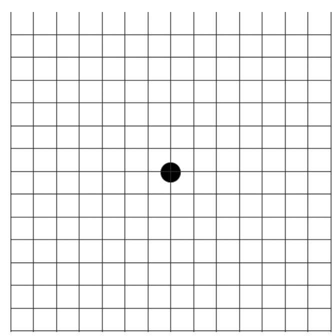
Using Representations

PART A: On the image at right, sketch and label vectors that represent the astronaut's velocity and acceleration.

PART B: The dot at right represents the astronaut standing in the space station. Draw a free-body diagram showing and labeling the forces (not components) exerted on the astronaut at the instant shown. Draw the relative lengths of all vectors to reflect the magnitudes of all the forces.



PART C: The astronaut drops a ball. On the following diagrams, sketch the velocity and acceleration vectors for the ball as seen by an observer outside the space station in an inertial frame of reference. These are NOT free-body diagrams.

After the ball is released and before it hits the floor	*After the ball hits the floor*
	

PART D: From the point of view of a person watching from outside the space station, what does the path of the ball look like?

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PART E: From the point of view of the astronaut inside the space station, what does the path of the ball look like?

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NAME ______________________ DATE ______________

Scenario

The mass of Mars is 1/10 times that of Earth; the diameter of Mars is 1/2 that of Earth.

Quantitative Analysis

PART A: Derive the equation for gravitational, g, due to a planet.

PART B: Let g be the gravitational field strength on Earth's surface. Derive an expression for the gravitational field on the surface of Mars without plugging in a value for the mass or radius of Mars. Your answer should be a number multiplied by g. For each line of the derivation, explain what was done mathematically (i.e., annotate your derivation).

Argumentation

PART C: A rock is dropped 2.0 meters above the surface of Mars. Does this rock take a longer or a shorter time to fall than a rock dropped 2.0 m above the surface of Earth? Justify your answer without using equations.

PART D: On the internet, a student finds the following equation for the time an object will take to fall to the ground from a height h, depending on the mass and radius of the planet the object is on: $t = \sqrt{\dfrac{2hG}{MR^2}}$

Regardless of whether this equation is correct, does it agree with your qualitative reasoning in Part C? In other words, does this equation for t have the expected dependence as reasoned in Part C?

________ Yes ________ No

Briefly explain your reasoning without deriving an equation for t.

PART E: Another student deriving an equation for the time it takes for an object to fall from height h makes a mistake and comes up with: $t = \sqrt{\dfrac{R^2}{2GMh}}$. Without deriving the correct equation, how can you tell that this equation is not plausible—in other words, that it does not make physical sense? Briefly explain your reasoning.

NAME ______________________ DATE ______________

Scenario

A student is given the following set of orbital data for some of Jupiter's moons and is asked to use the data to determine the mass M_J of Jupiter. Assume that the orbits of these moons are circular.

Orbital Period T *(seconds)*	***Orbital Radius*** R *(meters)*	*(s^2)*	*(m^3)*
2.08×10^7	1.12×10^{10}		
2.49×10^7	1.26×10^{10}		
4.05×10^7	1.71×10^{10}		
5.03×10^7	2.02×10^{10}		

Create an Equation

PART A: Write an algebraic expression for the gravitational force between Jupiter and one of its moons.

PART B: Use your expression from Part A and the assumption of circular orbits to derive an equation for the orbital period T of a moon as a function of its orbital radius R.

Data Analysis

PART C: Which quantities should be graphed to yield a straight line whose slope could be used to determine the mass of Jupiter?

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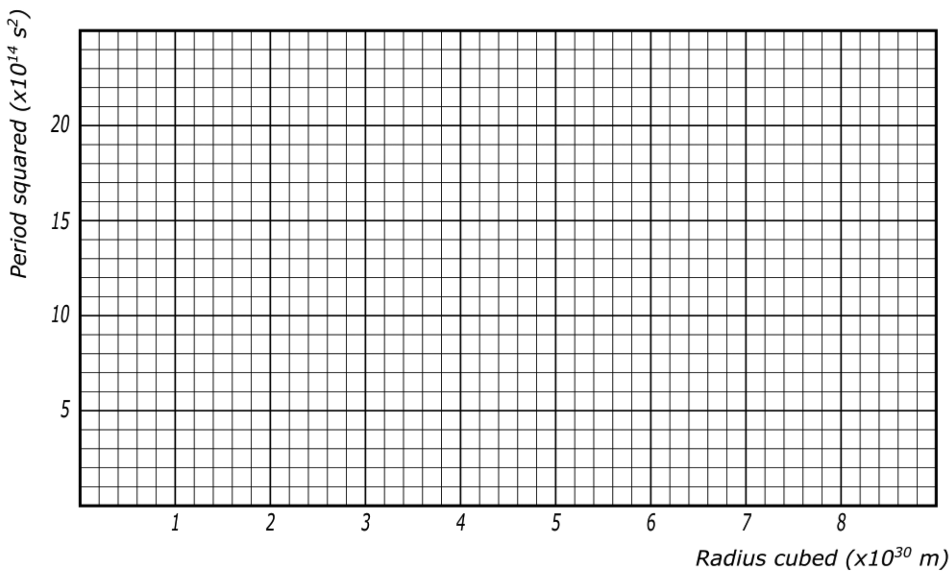
PART D: Complete the table by calculating the two quantities to be graphed. Label the top of each column, including units.

PART E: Plot the graph on the axes below. Label the axis with the variables used and appropriate numbers to indicate the scale.



PART F: Two identical probes are sent to study one of Jupiter's moons. Probe A is in geosynchronous orbit around the moon while probe B rests on the surface of the moon and rotates with the moon.

Rank the magnitudes of the following gravitational forces from greatest to least. If two or more quantities are the same, say so clearly.

a. The force of the moon on probe A

b. The force of the moon on probe B

c. The force of probe A on the moon

d. The force of probe B on the moon

e. The force of probe A on probe B

f. The force of probe B on probe A

Greatest ______ ______ ______ ______ ______ ______ Least

Justify your ranking.

NAME ______________________ DATE ______________

Scenario

Angela, Blake, and Carlos are studying the data table to the right, which shows the mass, orbital radius, and orbital period of four planets. They note that the orbital period increases but disagree about why this happens. Their arguments are as follows:

Planet	Mass [10^{24} kg]	Orbital Radius [10^9 m]	Orbital Period [years]
Mercury	0.330	57.9	0.241
Venus	4.87	108.2	0.616
Earth	5.97	149.6	1.00
Neptune	102	4495.1	164

Angela: "It appears that the more mass a planet has, the longer its period is. This is because more massive objects are more difficult to move, so these objects move slower in their orbits.

Blake: "No, all the planets move at the same speed around the sun, but planets with greater orbital radius must make longer circumference orbits, causing their orbital periods to be greater."

Carlos: "It is the case that farther-radius planets must make farther-circumference orbits, but the farther planets also go slower because there is less gravitational force acting on them."

For this problem, consider one planet of mass m making a circular orbit of radius R around the sun (mass M). Let v represent the speed of the planet as it orbits the sun and T be the orbital period.

Create an Equation

PART A: Beginning with basic equations for gravitational and centripetal force and an equation that relates speed and period of circular motion, derive an expression for the orbital period of this planet in terms of R, M, v, and physical constants as necessary. Note that it may be helpful for Part B for you to number your steps so that they can be referred to later.

Step 1	
Step2	
Step 3	
Step 4	
Step 5	
Step 6	

Argumentation

PART B: Your work in Part A can be used to support or refute the arguments of the three students. For each student, explain which aspects of their reasoning is correct (if any) and incorrect (if any) and cite steps of work from Part A (not your final answer) and explain how that step supports or refutes each aspect.

i. *Angela*	ii. *Blake*	iii. *Carlos*